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Analyzing Mexico's Indigenous internal migration dynamics through network centrality measures, 1990–2020

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Abstract

This study examines the internal migration patterns among Mexico's Indigenous population from 1990 to 2020. We begin by estimating the total interstate migration flows for Indigenous groups and employ an advanced interaction component model to identify migration flows that exceed expectations. This model allows us to detect significant deviations and patterns within the migration data. Additionally, we apply network analysis techniques to identify states that are central to these migration flows and categorize states into distinct communities based on their migration interactions. Our findings reveal that Indigenous migration exhibits higher-than-expected flows, particularly from the West Central and North regions of Mexico. By contrast, non-Indigenous migration shows greater flows, predominantly in the southern and central states. Through network analysis, particularly the use of eigenvector centrality, we identify Nayarit and Durango as key hubs for Indigenous migration, whereas Estado de Mexico and Ciudad de Mexico emerge as central nodes in non-Indigenous migration. Our study highlights the growing significance of Mexico's northern region, with Nuevo León playing a crucial role in Indigenous and non-Indigenous migration flow networks. This study's findings contribute valuable insights regarding the spatial dynamics of internal migration and the evolving migration patterns of Indigenous populations in Mexico.

KEYWORDS

eigenvector centrality, Indigenous population, internal migration, migration dynamics, migration flows, network analysis

1 | INTRODUCTION

Mexico has the largest Indigenous population in Latin America, with approximately 23.2 million Indigenous peoples, representing 19.4% of the nation's population Mexican National Statistical Office (Instituto Nacional de Estadistica y Geografia [INEGI], 2020). The country is home to over 60 distinct Indigenous ethnic groups, each with unique languages, cultural practices, pre-Hispanic economic systems, and social structures. The most widely spoken Indigenous languages—Nahuatl, Tzeltal, Mixtec, Tsotsil, Zapotec, Maya and Mazatec—account for 66.5% of the country's Indigenous language speakers. This diversity not only highlights the complex cultural landscape of Mexico but also underscores the importance of understanding the social and economic dynamics affecting these communities.

Analyzing internal migration flows is crucial for understanding the complex dynamics of population mobility within a country. This analysis is particularly important for examining the distinct patterns between Indigenous and non-Indigenous populations given the significant regional economic shifts since trade liberalization along with social challenges such as violence and natural disasters. These factors are closely related to migration patterns, especially among Indigenous populations. Additionally, Mexico has undergone substantial population growth and urban expansion, leading to the formation of metropolitan areas (Castillo Ramírez, 2019; Sobrino, 2014).

Migration is a critical factor in reshaping Mexico's Indigenous population. Indigenous people often migrate to support their families, sustain agricultural livelihoods, or seek social mobility (Robson & Berkes, 2011). Their migration includes movements not only from rural to urban areas but also from urban to urban areas. Clarifying these migration patterns and the differences between Indigenous and non-Indigenous migration is essential for several reasons. First, it uncovers the broader socio-economic trends affecting Indigenous and non-Indigenous populations and helps identify key regions involved in such patterns. Second, clarifying the differences is important because these groups may experience migration due to economic opportunities or environmental factors, with different underlying causes and implications.

In this study, we aim to address the following questions: What are the unique patterns of origin–destination migration flows among Mexico's Indigenous populations compared to non-Indigenous populations, and how have these patterns evolved over the past 30 years? To what extent can these migration flows be studied using network analysis? Finally, what states emerge as central for these migratory flows and can be identified as hubs of internal migration for the Indigenous population?

We employ two complementary approaches to analyze interstate migration flows. The first approach, a decomposition model, highlights specific origin–destination paths among the Indigenous population that deviate from general trends, identifying unusual patterns or significant changes over time. The second approach, network analysis, visualizes migration networks across regions and states, revealing key nodes and changes in economic opportunities, social structures, and environmental conditions. In the Mexican context, Indigenous migratory patterns have not received adequate attention, particularly regarding complex flows connecting origin and destination communities. Thus, this study aims to address this research gap by analyzing internal migration at the regional and state levels, which is essential for understanding the complex dynamics of migration within Mexico, especially when distinguishing between Indigenous and non-Indigenous populations.

The remainder of this paper is organized as follows. Section two includes a background discussion regarding main demographic and migration trends in Mexico for Indigenous a non-Indigenous population, while also including a comprehensive review of pertinent literature on internal migration. Following this, section three outlines the data sources used and the methodology employed to analyze migration flows. Section four then discussed the findings, and section five concludes with a final discussion, highlighting potential implications and avenues for future research.

2 | BACKGROUND

2.1 | Context of Indigenous population in Mexico

From 2015 to 2020, approximately 7.2 million Indigenous peoples aged five and older resided in Mexico, with 3.4% (approximately 244,800 individuals) changing their state of residence. In comparison, the non-Indigenous population, totaling approximately 108.4 million, had a similar percentage 3.4%, accounting to approximately 3.7 million people (Figure 1). Between 1990 and 2020, the annual growth rate of the Indigenous population was approximately 0.8%, considerably lower than the 2.3% observed for the non-Indigenous population. The migration patterns for both demographic groups showed fluctuations from 1995 to 2020, with a notable decline in mobility among non-Indigenous people during 2005–2010 and subsequent increases among both groups from 2015 to 2020.

Figure 2 illustrates a consistent decline in the crude migration rate among the non-Indigenous population, falling from 56 to 36.7 migrants per thousand between 1985 and 1990 and 2015–2020. In contrast, the migration rate of the Indigenous population remained relatively stable

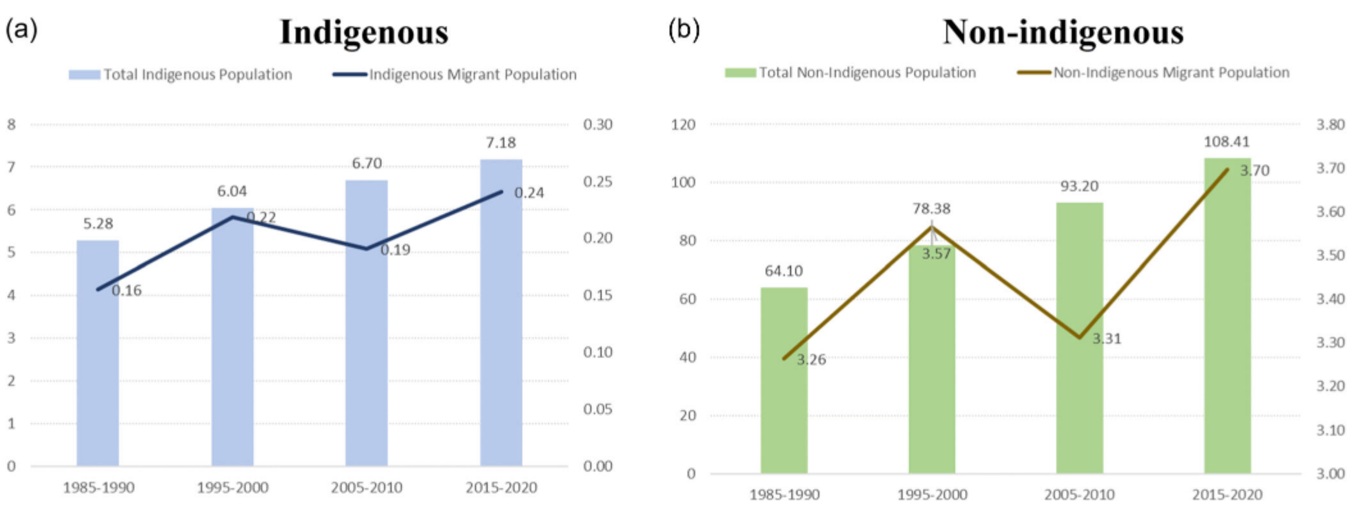

FIGURE 1 Total Indigenous and non-Indigenous population and internal migrants (millions). (a) Indigenous. (b) Non-Indigenous. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

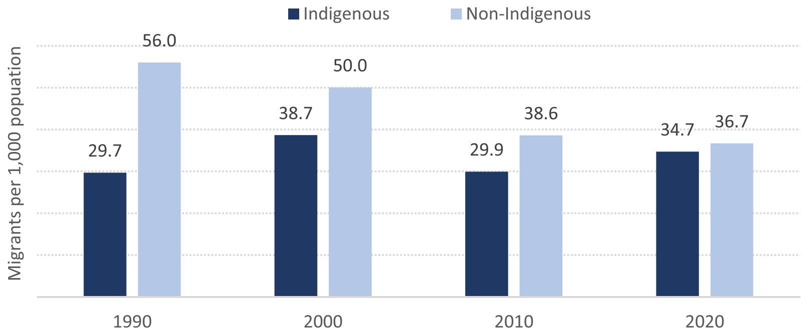

FIGURE 2 Crude interstate migration rates of Indigenous and non-Indigenous population. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

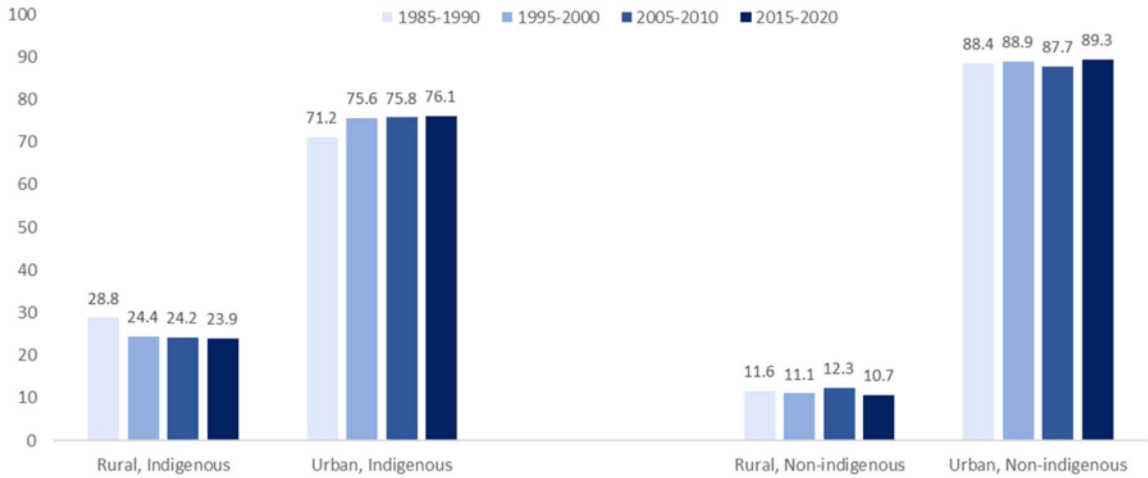

FIGURE 3 Interstate migration flows rural and urban for Indigenous and non-Indigenous population. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

during the same period. By the most recent period, the Indigenous crude migration rate reached 34.7, closely approaching the levels seen among the non-Indigenous population.

For both demographic populations in Mexico, interstate migration flows are predominantly urban, as shown in Figure 3. For non-Indigenous migrants, urban migration has remained remarkably stable, with approximately 89% of migration flows occurring to and from urban areas during the most recent period (2015–2020). This high percentage reflects a consistent preference for urban locales among non-Indigenous migrants. In contrast, Indigenous migration to urban areas, while also dominant, has shown slightly greater variability. By the latest period (2015–2020), 79% of Indigenous migrants moved between urban localities, an increase from 71% during the initial period (1985–1990).[1] This upward trend indicates that Indigenous populations are increasingly shifting toward urban areas, aligning their migration patterns more closely with those of the non-Indigenous population.

While national data provide insights into the main trends, our research categorizes Mexican states into four distinct regions—North, West, Central, and South—to better understand the regional dynamics of internal migration.[2] This classification allows us to examine demographic and migration patterns concerning each area's unique geographical, economic, and social characteristics, which is particularly valuable for studying the mobility of the Indigenous population within these varied contexts. Figure 4 illustrates this regional breakdown, where each region is represented by a consistent color—yellow for the North, green for the West, red for the Central, and blue for the South—used throughout this study. Each state is identified by an abbreviation, with details provided in Table A1 in the Appendix for reference.

Mexico's South region has historically been home to the highest concentration of the Indigenous population, maintaining stability over

[1]Typically, a locality in Mexico is considered urban if it has a population exceeding 2500 people. However, since the census does not track specific residence locations or their rural/urban status 5 years prior, we determine a locality urban or rural classification based on the proportion of its current population residing in urban areas of the corresponding census year. A similar approach is followed by Riosmena et al. 2023.

[2]The same regional classification has been applied in empirical work on internal migration, such as Partida (2015), and is followed by Banco de Mexico to classify economic regions.

FIGURE 4 Regional classification of Mexican states. *Source*: Own elaboration.

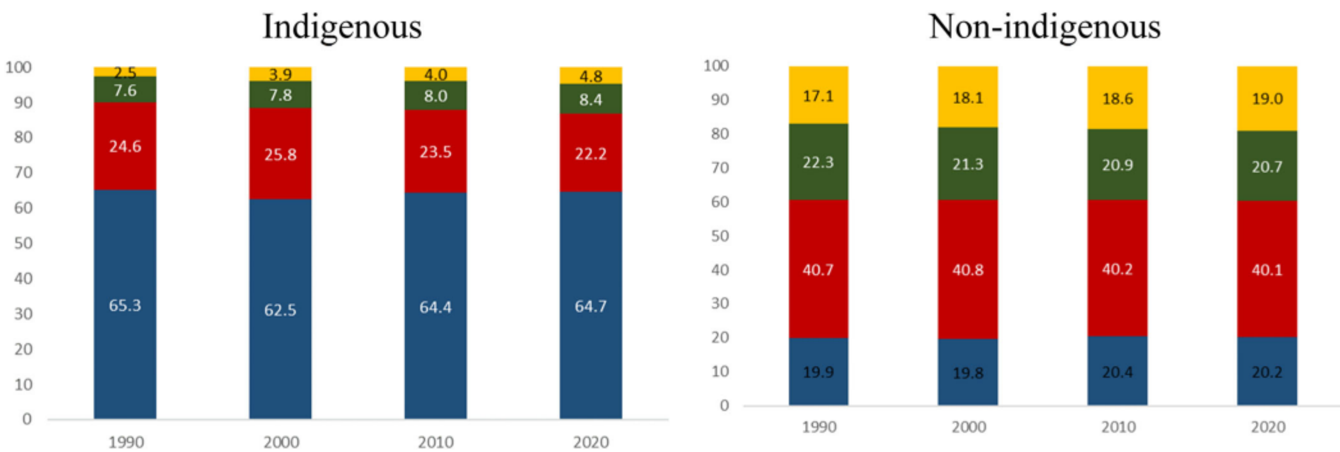

FIGURE 5 Distribution of Indigenous and Non-Indigenous population by region (percentage). *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

time with approximately 60% of the country's Indigenous people residing there (Figure 5). In contrast, the Central region has seen a marginal decline in its share of the Indigenous population, whereas the West Central and North regions have experienced increases, with the percentage of Indigenous peoples in the latter nearly doubling between 1990 and 2020. Conversely, the non-Indigenous population is more concentrated in the Central region, with approximately 40% residing there. This region is followed by the West Central, South, and North regions. These percentages have remained relatively stable over time, although the North region has seen a slight increase in its share.

This discussion highlights distinct and evolving regional populations and migration dynamics. To fully understand these patterns, the remainder of this study employs an analytical approach that examines internal migration flows through the lens of network interactions and centrality measures. This approach captures the complexity of interstate migration flows, elucidates the regional and state-specific dynamics driving these movements, and identifies states and regions that play pivotal roles in shaping the migration landscape of Indigenous and non-Indigenous populations.

2.2 | Literature review

The literature on internal migration in Mexico includes several approaches but generally focuses on specific cases within individual states or cities. For instance, Rangel Guzmán and Marín García (2014) documented migration patterns between Durango, Nayarit, and Sinaloa, particularly among *Tepehuanes* populations. These migrations, driven by social conflicts in the Sierra del Mezquital and Pueblo Nuevo regions of Durango, led families to establish new communities in urban and rural areas along the foothills, mountains, and northern coastal areas of Nayarit and southern Sinaloa. Velasco Ortiz (2007) links the Indigenous presence in cities to rural-to-urban migration, a key aspect of Mexico's broader urbanization and industrialization trends. In Tijuana, for example, Mixtec communities, along with reports of Purépecha migration, have been particularly prominent because of the city's border location and international migration.

Canabal (2009) highlighted the widespread nature of Indigenous population movements in Mexico. Significant migration flows have been observed among Purépecha, Maya, Zapotec, Mixtec (from Guerrero, Oaxaca and Puebla), Mazatec (from Oaxaca), Otomí (from Hidalgo, State of Mexico, Querétaro, Puebla and Veracruz), Nahua (from Guerrero, Hidalgo, State of Mexico, Veracruz and San Luis Potosí), Chinantec (from Oaxaca), Totonac (from Veracruz), Mazahua (from the State of Mexico), Choles (from Chiapas), and Mixes (from Oaxaca). These populations have settled in large-scale agricultural fields in the northwest and north-central regions, as well as in urban centers. Aguirre et al. (2022) noted that Quintana Roo has the highest rate of Indigenous migration in Mexico, with Indigenous immigrants mainly coming from neighboring states and settling in municipalities such as Benito Juárez and Solidaridad, which include Cancún and Playa del Carmen within the Riviera Maya.

Durin (2003) examined the Monterrey Metropolitan Area and noted a significant increase in Indigenous language speakers in the 1990 and 2000 censuses due to internal migration. This phenomenon reflects the settlement patterns in the city, underscoring the role of networks in migration, with many immigrants originating from San Luis Potosí, Veracruz, and Hidalgo often living in clustered (or gourped) communities on the urban peripheries.

Cárdenas (2014) identifies several new trends in internal migration: (a) an increase in the volume of Indigenous migration (b) a growing presence of women and children in migratory flows; (c) diversification of cities attracting immigrants; and (d) a transient and itinerant population responding to economic changes. Indigenous migration has gained significance due to the large population and its impact on the economic, political, and sociodemographic aspects of both origin and destination areas. This phenomenon correlates with the rapid expansion of medium-sized and small cities compared with other cities (Partida, 2000).

In this sense, internal migration is often associated with the movement of of population to areas with improved amenities and employment opportunities as compared with the origin places (Avila, 2002; Cárdenas, 2014; Pérez-Campuzano et al., 2018; Trujillo, 2006). Economic downturns and reductions in agricultural subsidies have intensified the longstanding exclusion and economic challenges faced by Indigenous communities who primarily rely on agriculture (Gravel, 2007; Robson et al., 2018). Migration serves as a crucial factor in demographic changes, influencing population distribution and Indigenous identities. The primary motivations for migration are subsistence, maintaining agrarian livelihoods, and seeking greater social mobility, reflecting broad rural migration trends (Arizpe, 1980).

Scholars have also considered cultural elements to gain a deeper understanding of migratory trends due to growing interest in comprehending the causes and effects of migration and the increasing significance of this phenomenon in the nation's demographic dynamics (De Haas, 2010; King & Skeldon, 2010). Few studies have examined aspects such as mortality, economic and productive activity, educational attainment, and service accessibility in communities with a significant population of native speakers (Espinoza et al., 2014; León-Pérez, 2019; Zuñiga et al., 2014). Other studies include ethnographic or anthropological studies focused on specific groups or settlements in large cities and rural regions, both domestically and abroad, particularly in the United States (Klooster, 2013; Ortiz, 2014). These studies aim to define and elucidate the socioeconomic variables influencing migratory movements, the personal and familial reasons behind migration, shifts in domestic and global movements of specific Indigenous groups, and the preservation of migrants' cultural identities.

Studies have revealed the increasing complexity of Indigenous migration patterns (Gallardo & Martín, 2023; Rubio, 2000). They found that Mexico's ethnic composition extended beyond traditional communities, extending to urban centers, border regions, and minor municipal areas. The study also observed a decline in the allure of the Mexico City Metropolitan Area for Indigenous migrants, who are now favoring other cities. This shift is attributed to the development of new economic zones that demand labor in sectors such as agriculture, services, and industry, often providing lower-skilled employment opportunities for Indigenous workers. Partida's work (2000) confirms this finding, identifying not only Mexico State and Mexico City but also Quintana Roo as key destinations for migrants fleeing rural deprivation. In addition, Granados Alcantar (2005) highlighted the rise of states such as Sinaloa and Quintana Roo as new magnets for Indigenous labor, suggesting that these regions have formed distinct labor markets without competing with Mexico City for migrants.

Given the nature of migration data, which identify places of origin and destination in terms of flows, network-based analysis offers several advantages when studying migration. The proposed model allows for the examination of complex relationships and interactions between different regions or nodes within the migration system. Network analysis has been used to study internal migration across the world. For example, Slater (2008) studied the hub and cluster structure of internal migration in the United States at the county level for two distinct periods 1965–1970 and 1995–2000, identifying a hierarchical community structure with cosmopolitan areas acting as hubs with longer-range links. Meanwhile, Goldade et al. (2018) compared internal migration during the housing boom and the subsequent recession, noting the relationship between network structure, geographical bounds, and community political affiliations. They found that high-degree nodes exhibited low clustering, whereas low-degree nodes exhibited high clustering, with stable migration dynamics over time and geographically confined communities. Charyyev and Gunes (2019) extended this analysis from 2000 to 2015, examining the impact of economic fluctuations on migration patterns and found considerable instability but also consistency in overall network characteristics. Pitoski et al. (2021) examined internal migration in Croatia and discovered power-law distributions in terms of degrees and strengths, reciprocal migration flows, and geographically bounded communities. Chen et al. (2021) conducted a visual network analysis of internal migration within England and Wales in 2019, noting movements within geographically close regions and the implications for policy planning. Carvalho and Charles-Edwards (2020) investigated migration networks in Brazil from 1980 to 2010, finding high reciprocity and hierarchical structures, with larger cities often forming long-range links and new flows typically occurring between established migration pairs.

While there is extensive literature on internal migration, no study, to the best of our knowledge, has specifically analyzed the internal migration flows among Mexico's Indigenous population using a network-based approach. The closest study in this area is by Caudillo-Cos and Tapia-McClung (2014), who examined the migration patterns of highly qualified populations using a network approach. However, their focus was on metropolitan areas and focused on in a single period (2005–2010) considering one segment of the population. Hence, this study aims to bridge this gap in the literature. By employing network representation, we can significantly enhance our understanding of Mexico's Indigenous population dynamics during almost a 30 year period.

3 | DATA AND METHODS

This study employs microdata from the General Census of Population and Housing for 1990, 2000, 2010 and 2020 to estimate interstate migration flows of Indigenous and non-Indigenous populations in Mexico. The migration flows are visualized as a network, with movements depicted from the state of origin to the destination state. The data collection in each census involved asking respondents about their place of residence at a specific point in the past, typically 5 years previously. Therefore, the migration periods under study are 1985–1990, 1995–2000, 2005–2010 and 2015–2020.

The data are drawn from 10% long-form samples of the Mexican Population and Housing Censuses, collected by the INEGI. For the 1990 Census, the 10% sample is an extract from the full census data. In subsequent census years (2000, 2010 and 2020), the 10% samples are designed to be representative at the national, state, and municipal levels. These samples are stratified to accurately reflect the rural–urban composition within each state, capturing the diversity of localities by size (INEGI, 2003, 2011, 2021). Stratification ensures that the data provide a comprehensive picture of migration patterns across different regions and settlement types in Mexico, facilitating a detailed analysis of interstate migration flows and their evolution.

Although intrastate migration (change in municipality residence within a state) plays also a role in population movements, this study focuses on interstate migration for several reasons. First, interstate migration captures significant population movements across large geographic areas, providing a comprehensive overview of how people relocate over considerable distances and across different regions. This enables the study to identify major migration trends and clarify the factors driving these movements on a national scale. Furthermore, by analyzing interstate flows, we gain insights into regional interactions and connections. This approach reveals how states function as origins and destinations for migrants, highlighting the economic, social, and demographic ties linking them. Further, interstate migration serves as an ideal proxy for long-distance movement, helping to effectively capture the dynamics and correlates of mobility. This focus remains relevant even if mobility data were to include all changes in residence, as intramunicipal moves are, by definition, within the same state and do not reflect broader regional dynamics (Riosmena & Balk, 2024).

In identifying Indigenous populations, we used a linguistic criterion. This approach offers a comprehensive understanding of migration dynamics over as the 30-year period because it aligns with data collected in each of the population censuses used in this study. Languages are a practical and effective way to identify Indigenous people, given that language preservation is often considered the most representative and objective marker of Indigenous identity compared to other ethnic identifiers such as customs, values, or daily practices (Granados Alcantar & Quezada Ramírez, 2018). The criterion includes all residents aged 5 years and above, as recorded in censuses. It excludes children aged zero to four and those with unspecified ages but provides a clear and practical means of defining the Indigenous population as individuals aged five and above who identify as speakers of an Indigenous language (Corona et al., 2010).

Classifying Indigenous populations based on language proficiency is the most common approach in empirical studies. However, recently, self-identification has recently been incorporated into as an alternative method. However, this new approach has certain limitations. Villarreal (2014) found that using self-identification to identify Indigeneity tends to capture a symbolic, less tangible form of ethnicity, often representing a population that is relatively less disadvantaged. Similarly, Flores et al. (2023) argue that the identification question used can significantly influence the kind of ethnicity recorded. For example, they note that the 2010 census in Mexico included an identification question that resonated with a broad segment of the population. This question likely appealed to Mexicans because it addressed a symbolic type of ethnicity—one that is based on subjective belonging rather than concrete ties to specific subgroups or the necessity of communal living, supporting the "symbolic ethnicity" hypothesis, which proposes that the more symbolic the type of ethnicity conveyed by identification questions, the larger and less disadvantaged the captured population will be (Flores et al., 2023). Given these insights, language proficiency remains a practical and robust criterion for identifying Indigenous populations, providing a clear, objective measure compared with self-identification, which is subjective and carries potentially broader interpretations.

As stated above, the analytical framework of this study utilizes data on migration flows, specifically analyzing the origin and destination of these flows. We apply two complementary approaches to understand the dynamics and specific characteristics of the migration network, which are described in the following subsections.

3.1 | Decomposition model of internal migrant flows

In the context of Mexico's complex migration landscape, adopting a multiregional (*state-to-state*) migration system for migration flows is inherently challenging due to the potential number of movements across the country. Managing this complexity requires presenting the largest absolute numbers, which can be effective for understanding major migration streams that often correspond to regions with significant populations and close spatial proximity. However, this approach may overshadow smaller yet potentially significant migration streams that may be of interest. Hence, it is essential to consider standardized migration streams and explore various presentation methods to identify nuanced migration trends (Holland & Plane, 2001).

Various standardization methods have been proposed to highlight the most salient streams, each with its benefits and drawbacks. For example, calculating in- and out-migration rates based on standardized population at risk provides a consistent framework, although it may not always perfectly align with real-world migration behaviors (Holland & Plane, 2001). Calculating the in-migration rate in this manner allows for comparability with the out-migration rate over a particular period because they share the same denominator; however, this approach is not consistent with the traditional definition in terms of 'population at risk'. Similarly, the net migration rate is not a true demographic rate in terms of the population at risk, as no one is specifically at risk of being a net migrant.[3]

Rogers (1990) develops a spatial interaction model that offers a realistic depiction of migration by linking directional movements to populations at risk and measuring true propensities to migrate. Specifically, it considers aggregate migration flows as part of a multiregional system, where the movement from each origin region impacts the population dynamics of multiple destination regions. This model not only considers population sizes at both the origins and destinations but also incorporates an 'interaction' factor between each origin–destination pair, which is crucial for accurately representing the complex dynamics and data structures associated with migration flows (Raymer et al., 2017; Rogers et al., 2002).

[3]As described by Holland and Plane (2001), the population in the state is clearly not at risk of moving there if they already live there. The actual population at risk in this case is everyone outside the state—not a particularly useful or practical figure because theoretically it includes everyone in the world not already living in the region. Similarly, the net migration rate is not a true demographic rate in terms of the population at risk. Clearly, no one is at risk of becoming a net migrant. In common practice, the net migration rate for a given state is calculated as the net migration rate for the state divided by the state's population. However, net migration rate is widely used in migration studies despite the identification of several deficiencies in mobility.

TABLE 1 Notation for an origin-destination migration flow table.

Region of origin	Region of destination				
	North	West Central	Central	South	Total
North	n_{11}	n_{12}	n_{13}	n_{14}	n^*_1
West Central	n_{21}	n_{22}	n_{23}	n_{24}	n^*_2
Central	n_{31}	n_{32}	n_{33}	n_{34}	n^*_3
South	n_{41}	n_{42}	n_{43}	n_{44}	n^*_4
Total	n^*_1	n^*_2	n^*_3	n^*_4	n^{**}

Source: Own elaboration based on Raymer et al. (2017).

Bilateral migration data are commonly represented in square contingency tables, with of-diagonal entries (the cell in the intersection of row i and column j, $I \neq j$) containing migration measures from origin i to destination j. Consider two hypothetical migrant stock tables for consecutive years (t and $t+1$) in Table 1. For simplicity, we represent the migration network by region, resulting in a 4×4 matrix. In our detailed analysis, we estimate migration flows at the state level, creating a 32×32 matrix. Table 1 illustrates migration flows between the North, West, Central, and South regions, where migration from origin region i to destination region j is denoted by n_{ij}. The total number of out-migrants from each region is denoted as n_i^*, the total number of in-migrants by n^*_j, and the overall level of migration by n^{**}. At the regional level, Rogers et al. (2002) suggest that diagonal elements should be removed, that is, intraregional migration should be omitted by replacing diagonal elements with structural zeros. This improves the predictive capability of the independence model while maintaining its useful properties of consistent marginal totals.[4]

Where n_{ij} is denoted as follows:

$$n_{ij} = (T)(O_i)(D_j)(OD_{ij}) \quad (1)$$

where T is the total number of migrants (n^{**}), O_i corresponds to the proportion of all migrants leaving area i (n_i^*/n^{**}), and D_j is the proportion of all migrants moving to area j (n^*_j/n^{**}). An important component of Equation (1) is the interaction component OD_{ij}, defined as follows:

$$OD_{ij} = n_{ij}/(T)(O_i)(D_j) \quad (2)$$

This interaction component is also referred to as the ratio of observed to expected migration (in case of no interaction). In this study, the interaction component is particularly important for assessing the interstate migration flows for Indigenous and non-Indigenous populations that may otherwise be masked by general trends or not be apparent upon analyzing raw migration data. This method allows us to

[4]The resultant independence model predicts interregional migration flows under the conditions that origin and destination are independent and that intraregional migration is omitted from the data (conditional independence model).

discern whether specific state-to-state flows are disproportionately high or low, considering the general expected migration tendencies based on the population sizes at origin and destination.

Additionally, this approach, also known as a multiplicative component model, can be adapted to include additional attributes such as age and sex, making it useful for forecasting regional migration flows (Raymer et al., 2017; Raymer et al., 2020). Although these capabilities extend the model's utility, exploring these adaptations and their applications in forecasting are beyond the scope of this study and represent potential avenues for further research.

3.2 | Network measures

As previously mentioned, migration flow data are represented by a matrix within a directed network, involving states or regions characterized by immigration (in-links) and emigration (out-links) and the volumes associated with these flows. Specifically, a network is a catalog of a system's components—often called nodes or vertices (V)—and the direct interactions between them, called links or edges (E). Consequently, for a given graph or network G = (V, E) with |V| vertices, let A = ($a_{vt,t}$) be the adjacency matrix of network G, where $a_{vt,t} = 1$ indicates a link from i to j and $a_{vt,t} = 0$ indicates no such link.

Centrality measures are key concepts in network analysis used to identify the most important nodes in a network. These measures help understand the role and influence of each node, which can represent individuals, organizations, states, or other entities in various contexts. Among these measures, eigenvector centrality considers not only the number of direct connections a node has but also the importance of the nodes to which it is connected. In other words, connections to highly influential nodes increase a node's eigenvector centrality more than those to less influential nodes. This measure is particularly useful in networks in which influence and connectivity are distributed unevenly. Unlike degree centrality, which only counts direct connections, eigenvector centrality evaluates a node's influence based on the centrality of its neighbors. This enables it to measure a node's importance within the network, reflecting its proximity to other central actors (Porat & Benguigui, 2021). For example, when studying international migration networks, eigenvector centrality highlights key countries that are central hubs of immigration and their direct connections through migration flows (Akbari, 2021; Aleskerov et al., 2017). Therefore, a high-ranked state in terms of eigenvector centrality is connected to other high-ranked states through significant migration flows, emphasizing its role in the migration network (Charyyev & Gunes, 2019).[5]

Intuitively, a position is central, with respect to eigenvector centrality, if it is connected to other positions which have many connections (Bienenstock & Bonacich, 2022). In the context of Mexico's internal interstate migration, eigenvector centrality identifies states that are not only central in terms of direct migration flows but also connected to other highly influential states. This can highlight states that play crucial roles in migration networks, whether as major origins, destinations, or transit points and aids in understanding broader migration dynamics and planning targeted interventions. Although some states might not have the highest number of direct connections, a high eigenvector centrality score indicates that they hold strategic positions due to their links to influential states. These factors make them significant hubs in the migration network, either as destinations or sources, and they therefore play a crucial role in the country's overall migration dynamics. Centrality measures such as eigenvector centrality, are commonly used to analyze migration flows, both internally and internationally, offering insights into the structure and influence of states within migration networks. Researchers such as Aleskerov et al. (2017), Charyyev and Gunes (2019), Akbari (2021), and Porat and Benguigui (2021) have applied these metrics to study migration patterns and network structures effectively.

In the context of Mexico's internal interstate migration, community detection is vital for identifying key regional hubs and understanding migration patterns. Methods such as Louvain community detection optimize modularity to group states based on migration connections, revealing natural clusters of states (or group of states) with significant migration ties. This approach enhances our understanding of states' interactions within a broader migration network, providing insights that are crucial to policymaking, resource allocation, and strategic interventions aimed at effectively managing migration flows across different regions of Mexico. The Louvain method groups nodes (states) into communities by iteratively optimizing modularity (Koylu & Torkashvand, 2023). Modularity measures the strength of division within a network by comparing the density of links within communities to those between communities. High values indicate dense connections within communities and sparse connections between them, which helps assess how well a network can be segmented into distinct groups. The Louvain algorithm leverages this concept to identify optimal communities by initially assigning each node to its community and then merging nodes as well as communities iteratively to maximize modularity. This process continues until no further improvement is possible, resulting in a hierarchical, multi-level decomposition of the network.

4 | RESULTS AND DISCUSSION

Figure 6 presents the initial set of results, which visualizes the total migration flows through the network structure. It distinguishes between Indigenous (Panel A) and non-Indigenous (Panel B) migrants over different periods, with the edge colors indicating the regions involved. During the initial analysis period (1985–1990), Indigenous migration was substantial between the South and Central regions—unsurprisingly, the two most populated regions in the country. Oaxaca (OAX) stands out as a major origin state, with substantial

[5]Other common centrality measures include degree centrality, which counts the number of direct connections a node has; betweenness centrality, which identifies nodes that act as bridges along the shortest path between other nodes; and closeness centrality, which measures how close a node is to all other nodes in the network. We focus on exploring eigenvector centrality attributes given the purposes of this study.

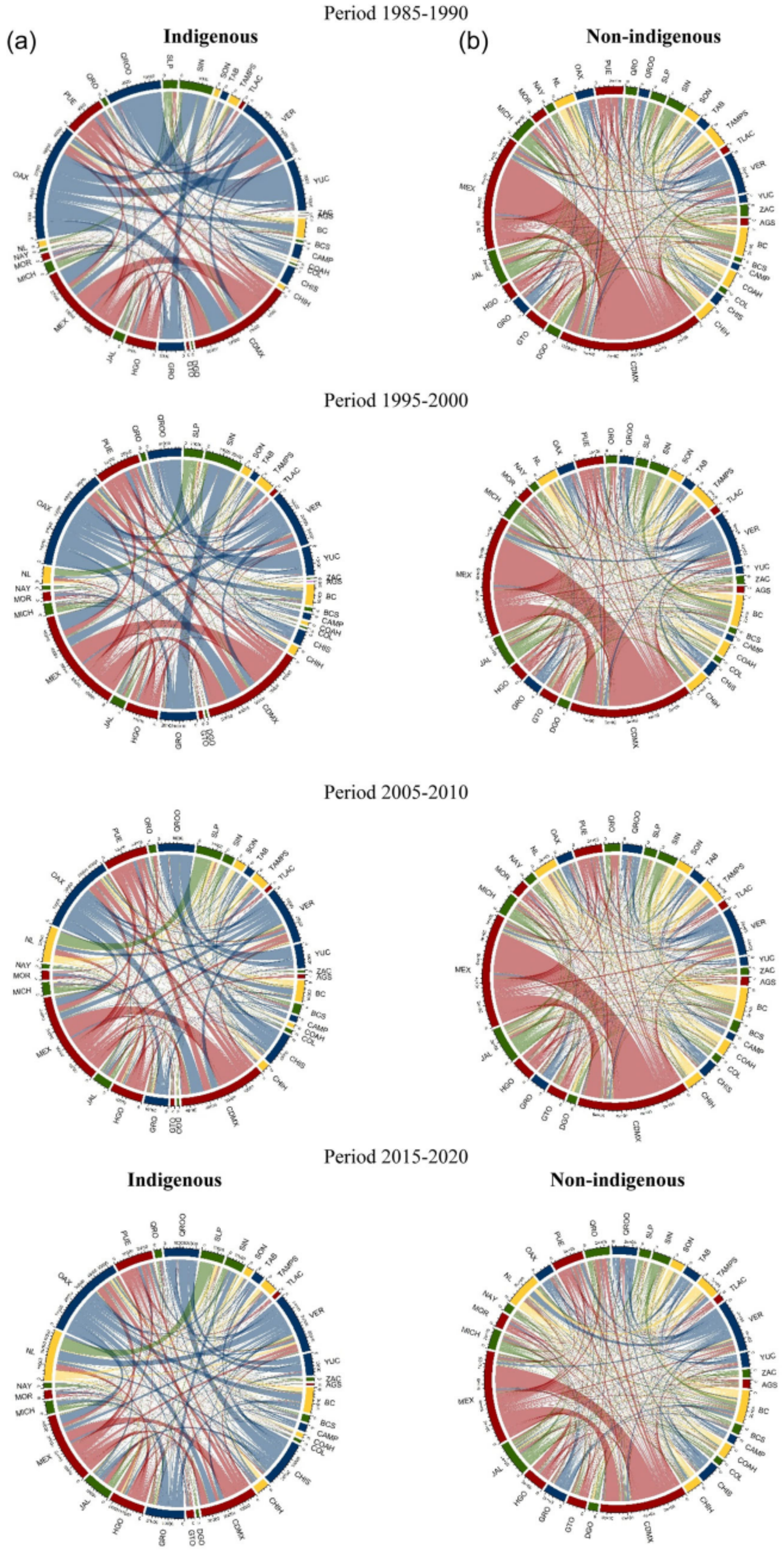

FIGURE 6 Interstate migration flows for Indigenous and non-Iindigenous population. (a) Indigenous. (b) Non-Indigenous. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

flows directed toward Mexico City (CDMX), the State of Mexico (MEX), Veracruz (VER), San Luis Potosí (SLP), and, to a lesser extent, Baja California (BC). Notable movements can also be seen from Yucatán (YUC) to Quintana Roo (QROO) and from Mexico City (CDMX) to the State of Mexico (MEX). Puebla demonstrates consistent migration links within the Central region, particularly with Veracruz (VER), Puebla (PUE), the State of Mexico (MEX), and Hidalgo (HGO). Conversely, the migration flow of non-Indigenous population is predominantly concentrated in central states such as Mexico City (CMX) and the State of Mexico (MEX), with Mexico City receiving inflows from nearly all other states.

In the 1995–2000 period, the southern region experienced a higher out-migration rate than in-migration rate. Significant flows are observed from Oaxaca (OAX) to Mexico City (CDMX) and the State of Mexico (MEX). Other key movements included migration from Yucatán to Quintana Roo, and from Guerrero and Oaxaca to San Luis Potosí. The central region has remained a primary destination for Indigenous migrants, especially from southern states, with Oaxaca as the primary origin. These migrants largely relocated to Mexico City and the State of Mexico. Puebla also saw significant migrant inflows, mainly from Veracruz. Meanwhile, migration patterns of non-Indigenous migrants during this period mirrored those of the previous period.

From 2005 to 2010, circular migration flows markedly intensified between the southern states of Yucatán and Quintana Roo, with Quintana Roo emerging as a significant attractor of migrants from Veracruz and Chiapas. Mexico City and the State of Mexico continued to be the principal recipients of migrants, with the State of Mexico gaining popularity among central states. Additionally, there were notable flows from the West Central and South regions to northern states, including movements from San Luis Potosí, Veracruz, and Hidalgo to Nuevo León. For non-Indigenous migrants, compared with the previous periods, migration flows within the central states decreased, whereas northern states began to gain relevance.

In the final period, from 2015 to 2020, the patterns previously observed for Indigenous and non-Indigenous migrant populations became more pronounced. Indigenous migrant flows between states in the central region further decreased, while southern states diversified migration patterns, sending migrants to a broader range of states across different regions. Nuevo León emerged as a significant attractor of migrant flows, particularly Indigenous migrants. For non-Indigenous migrants, migration interactions within the central region diminished, especially between the State of Mexico and Mexico City, although migration remained significant relative to other origin–destination flows. The northern states also increased their presence as attractors of non-Indigenous migrants, reflecting a shift in migration dynamics across the country.

Larger populations typically generate more migrants and have a wider range of connections; therefore, there is a need to account for the effect of population size on migration volumes. Figure 7 presents the network visualization of migration flows based on the interaction component OD_{ij}, as described in Equation (2), for Indigenous and non-Indigenous populations across different periods. The interaction component measures the ratio of observed to expected migration flows and highlights significant deviations from typical patterns. The study found that the most populated states—whether Indigenous or non-Indigenous—do not necessarily exhibit the greatest migration flows. For Indigenous migrants, higher-than-expected migration flows are observed, particularly originating from the West Central region and, to a lesser extent, the North region, (see Figure 7).[6] The consistent migration patterns include the following: Durango to Nayarit (DGO-NAY) and vice versa; Coahuila to Chihuahua (COAH-CHIH); Aguascalientes to Querétaro (AGS-QRO); and Zacatecas to Aguascalientes (ZAC-AGS). These flows indicate strong, consistent migration patterns within these areas that exceed expected trends based solely on population size. Other significant interaction flows occur between states in different regions, such as from Quintana Roo to Yucatán (QROO-YUC) in the south and from Nuevo León to San Luis Potosí (NL-SLP), linking the North to the West Central region.

Meanwhile, non-Indigenous migration patterns show higher-than-expected flows, particularly among southern states, although not necessarily the most populated states. The southern region exhibits strong interaction flows, especially between Quintana Roo and Yucatán (QROO-YUC), Tabasco and Campeche (TAB-CAMP), and Campeche and Yucatán (CAMP-YUC). The northern region also shows greater-than-expected interaction components, with significant flows from and to Nuevo León (NL), between Coahuila and Durango (COAH-DGO), from Durango to Chihuahua (DGO-CHIH), and between Zacatecas and Aguascalientes (ZAC-AGS).

In summary, the West Central region consistently shows the highest proportion of both interregional and intraregional migration flows by Indigenous and non-Indigenous migrants across all periods analyzed. For non-Indigenous migration, the southern region experienced a significant increase in both interregional and intraregional flows. The North region has experienced a slight increase in both types of migration flows for Indigenous migrants. Conversely, the Central region has shown a reduction in migration flows for both Indigenous and non-Indigenous groups over time. Despite these changes, the West Central region continues to dominate non-Indigenous migration in both interregional and intraregional flows.

The interaction component (OD_{ij}) of interstate migration flows between Indigenous and non-Indigenous populations can be effectively analyzed using network measures such as eigenvector centrality. These measures not only the direct connections of a state within the migration network but also the importance of the states to which it is connected. For Indigenous migration flows, states with high eigenvector centrality are influential hubs, serving as major sources and destinations of migrants. Figure 8 illustrates the evolution of estimated eigenvector centrality across different periods based on interaction flows (OID_{ij}), which are ranked in ascending order for the latest period (2015–2020). Panel A depicts interaction migration flows among Indigenous populations, whereas Panel B depicts those for non-Indigenous populations.

[6]The estimates used to generate this figure are available upon request.

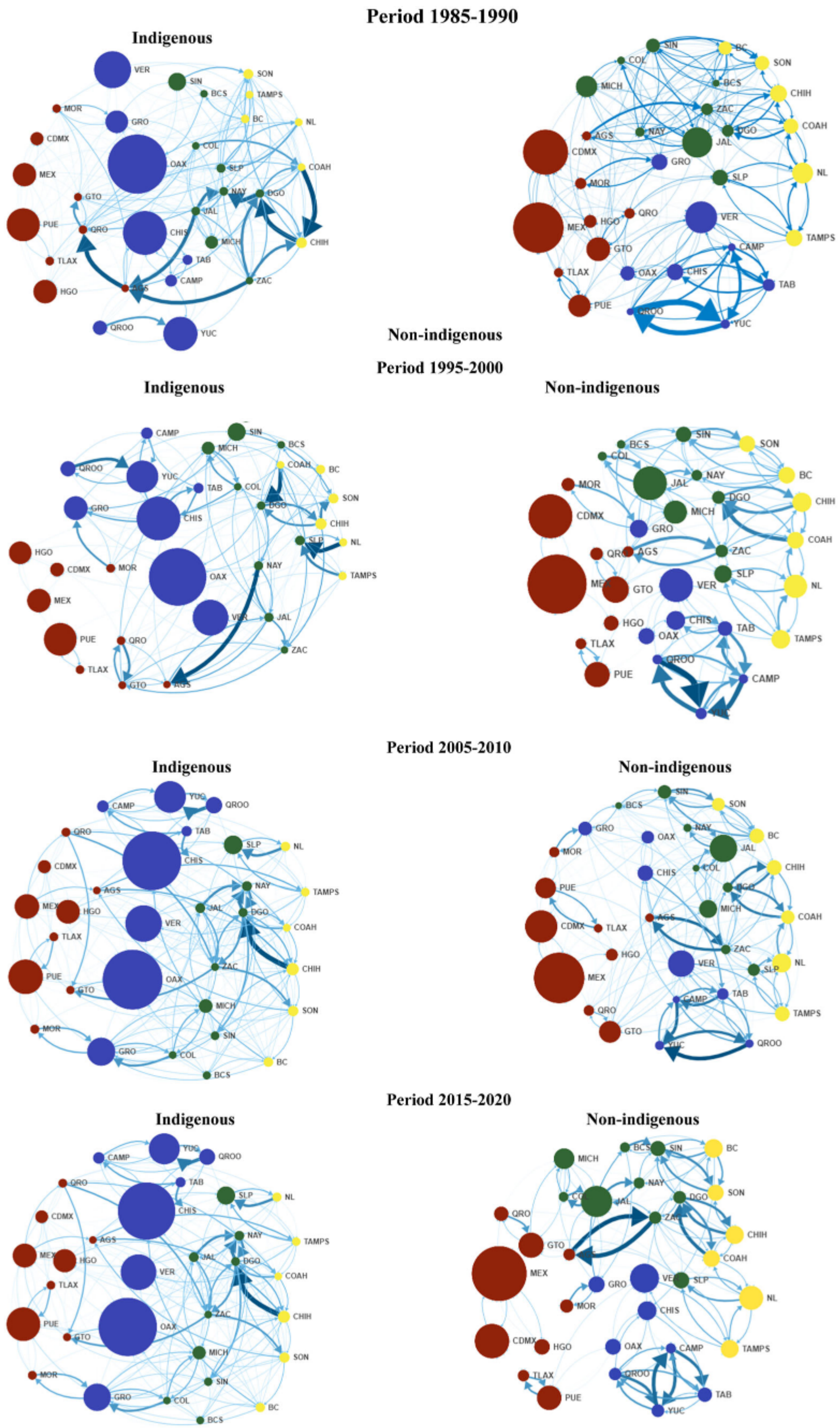

FIGURE 7 Interaction component (OD_{ij}) of intestate migration flows for indigenous and Non-Indigenous population. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020. Network flows represent the interaction component for values greater than 2. The size of the node is proportional to the corresponding population.

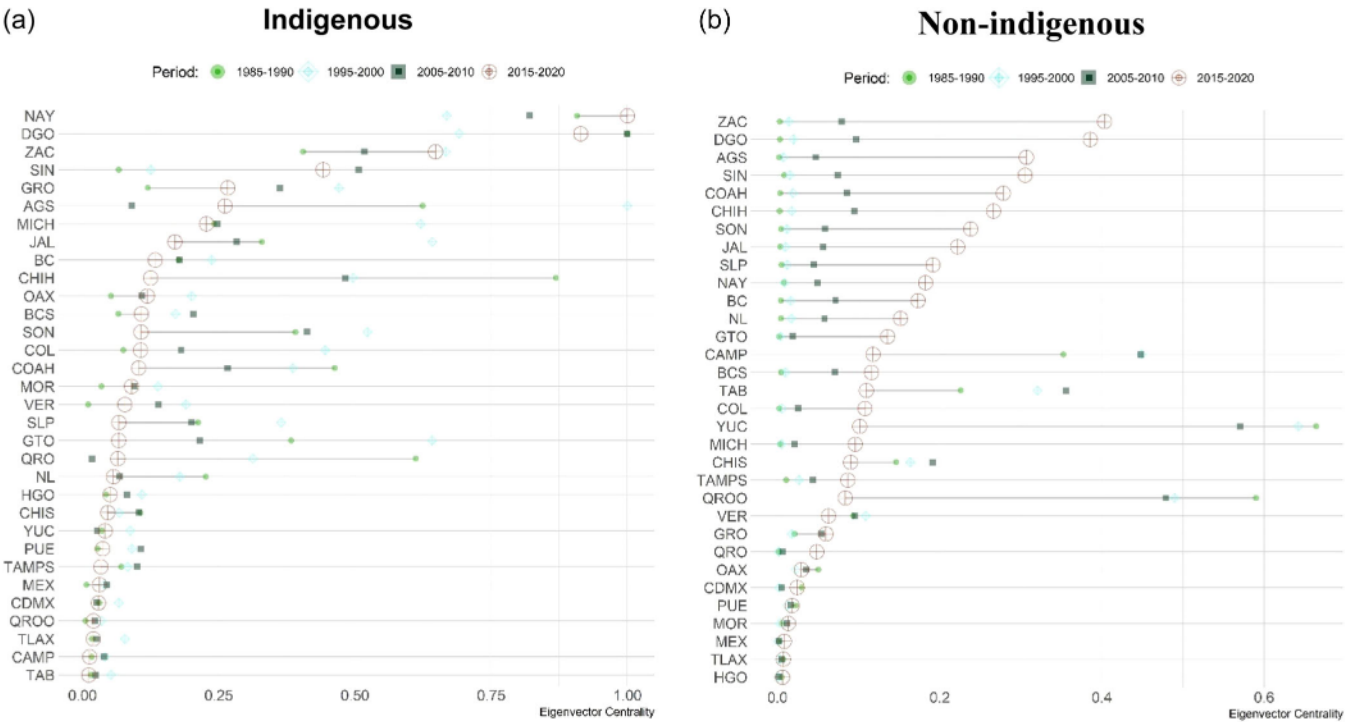

FIGURE 8 Evolution of eigenvector centrality of interaction (IOD_{ij}) flows. (a) Indigenous. (b) Non-Indigenous. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

The results highlight the significant role of the West Central region in Indigenous migration flows, with five states—Nayarit (NAY), Durango (DGO), Zacatecas (ZAC), Michoacán (MICH), and Jalisco (JAL)—ranking among the top 10 states with the highest eigenvector centrality values. Additionally, two states from the North, BC and Chihuahua (CHIH), along with one state each from the Central (Aguascalientes (AGS)) and South (Guerrero [GRO]) regions, were also in the top 10. Notably, the largest reductions in centrality were observed for Coahuila (COAH), Sonora (SON), and Aguascalientes (AGS), indicating dynamic changes in the Indigenous migration network.

For non-Indigenous migration flows, the West Central region remained significant, with five states among the top 10: Zacatecas (ZAC), Durango (DGO), Jalisco (JAL), San Luis Potosí (SLP), and Nayarit (NAY). The North region follows three states: Coahuila (COAH), Chihuahua (CHIH), and Sonora (SON). The Central and South regions are each represented by one state, Aguascalientes (AGS), which has shown a remarkable increase over the periods analyzed. In contrast, states with the most considerable reductions in eigenvector centrality include Yucatán (YUC), Quintana Roo (QR), and Mexico City (CDMX), highlighting a shift toward the Central West region over the southern and central regions.

The distinction between interaction and total flows is clearly shown in Figure 9. This figure shows that the top 10 states with the highest eigenvector centrality flows are predominantly from the Central and South regions. Specifically, Panel A illustrates eigenvector centrality for total Indigenous flows. The Central region, includes the State of Mexico (MEX), Mexico City (CDMX), and Puebla (PUE). The southern region includes Oaxaca (OAX), Quintana Roo (QROO), Yucatán (YUC), and Veracruz (VER). The western central region is represented by Sinaloa (SIN) and San Luis Potosí (SLP) while Nuevo León (NL) represents the North. For non-Indigenous total flows, the eigenvector centrality ranking shows a predominance of the Central region with five states: the State of Mexico (MEX), Mexico City (CDMX), Hidalgo (HGO), Querétaro (QRO), and Puebla (PUE). In the northern region, Baja California (BC) and Nuevo León (NL) are significant, with Quintana Roo (QR) from the South and Jalisco (JAL) from the West Central region rounding out the top 10.

The comparison between interaction and total flows revealed distinct regional migration patterns. Interaction flows highlight strong connections within the Western, Central, and Southern regions. In contrast, total flows, whether Indigenous or non-Indigenous, demonstrate a more diverse distribution across regions. As the Central region continues to exhibit strength, states from the North, such as Nuevo León (NL) and Baja California (BC), feature prominently in non-Indigenous total flows, reflecting their attractiveness as destinations beyond regional boundaries. These findings underscore the complex dynamics of migration networks, where interaction flows emphasize regional hubs of connectivity, whereas total flows reveal broader migration patterns across Mexico.

The final set of results involves community detection of migration flows among states for Indigenous and non-Indigenous migrants, considering interaction and total migration flows, as shown in

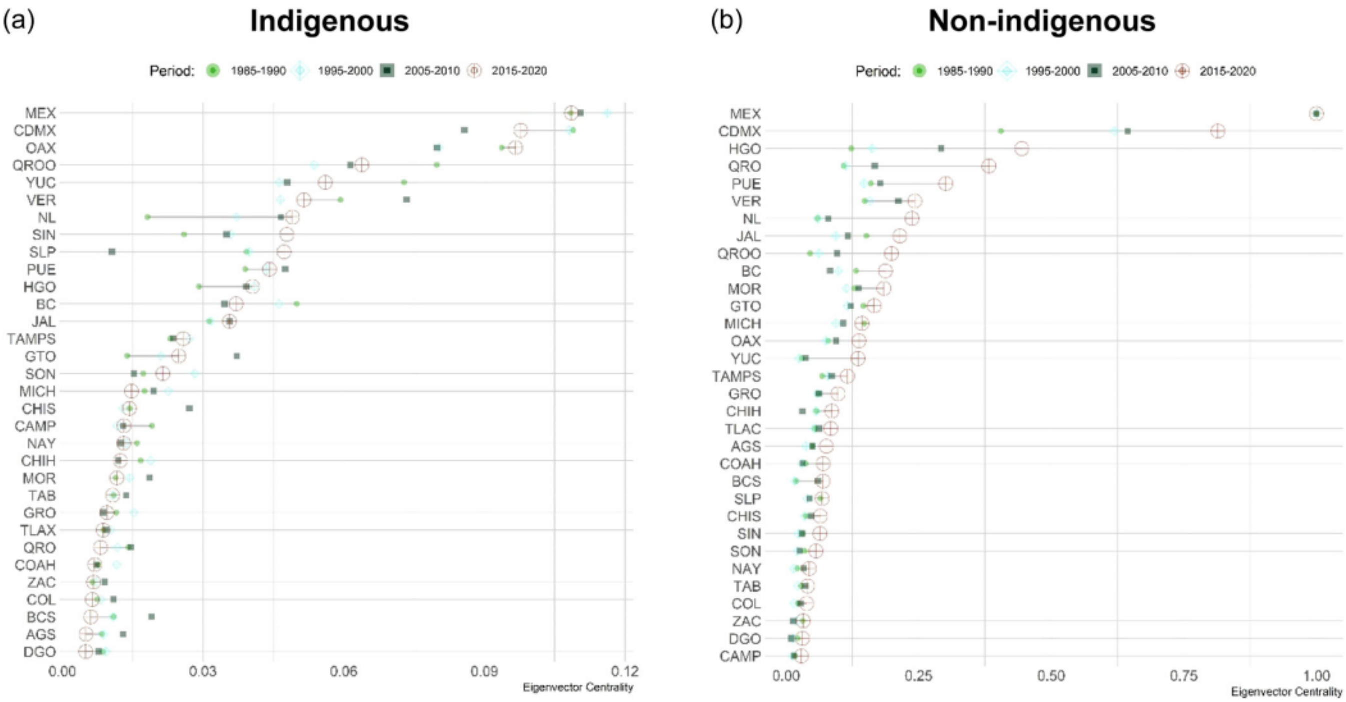

FIGURE 9 Evolution of eigenvector centrality for total flows. (a) Indigenous. (b) Non-Indigenous. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

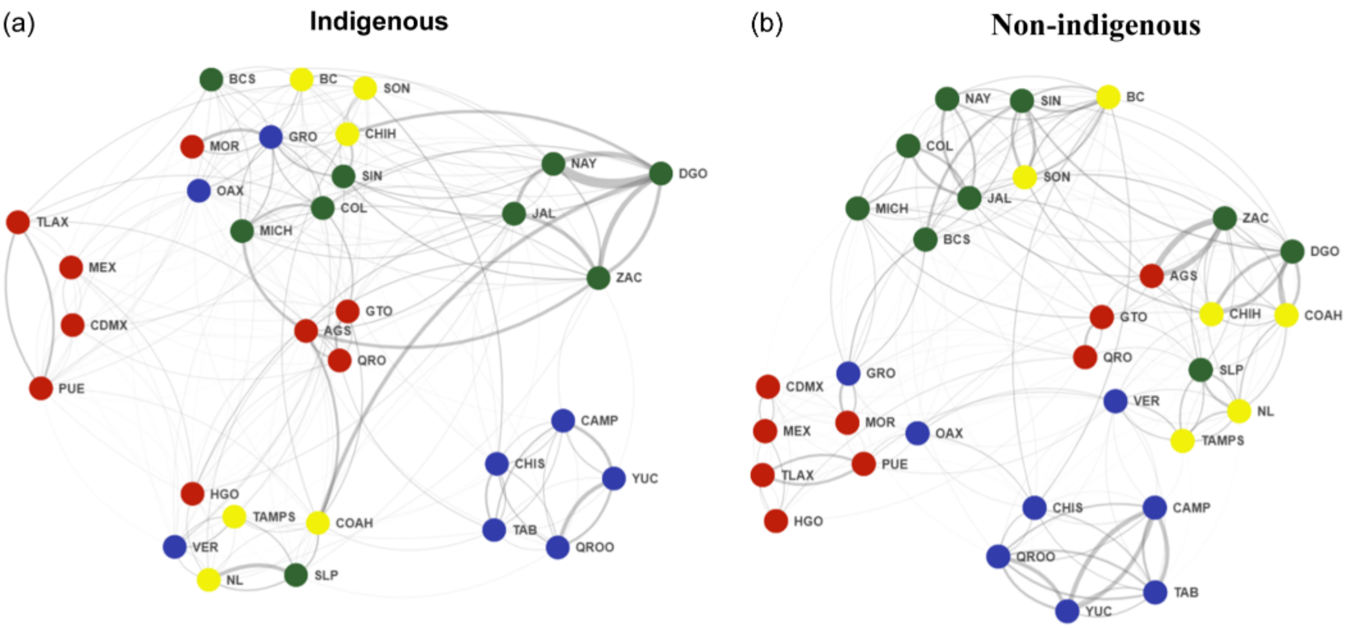

FIGURE 10 Network communities for interaction (IOD_{ij}) flows. (a) Indigenous. (b) Non-Indigenous. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

Figures 10 and 11, respectively. The analysis, covering the period from 2015 to 2020,[7] utilizes Louvain community detection to identify distinct groups or communities of states based on migration flows. This method highlights which states are more interconnected and share similar migration patterns, thus providing a clearer picture of regional migration dynamics. Although the Louvain method does not enforce spatial contiguity, the resulting communities may group

[7]These results associated to previous periods are available upon request.

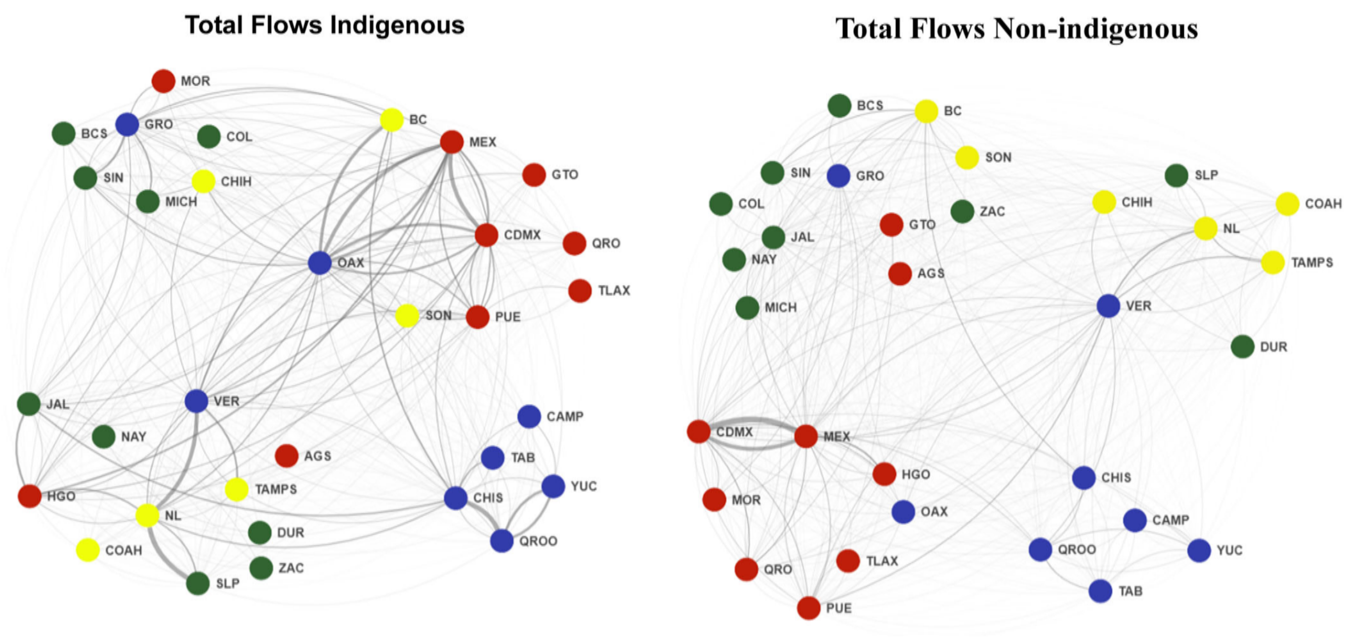

FIGURE 11 Network communities for total migration flows. *Source*: Own elaboration with data from Population Census 1990, 2000, 2010 and 2020.

states with strong migration connections even if they are geographically distant.

For interaction migration flows, six and four communities were identified for Indigenous and non-Indigenous migrants. respectively. These findings align with previous results, showing Indigenous flows grouped into communities, such as one consisting of central states (MEX, CDMX, TLAX, PUE, GTO, AGS and QRO); another with central-western states (DGO, NAY, JAL, ZAC); a community of purely southern states (CAMP, YUC, QROO, TAB and CHIS); and two communities with mixed regions (HGO, TAMPS, COAH, SLP, NL and VER) and (BCS, SON, CHIH, SIN, COL, MICH, OAX, GRO, MOR and BCS). For non-Indigenous interaction flows (see Figure 11), the resulting communities are predominantly composed of mixed states, with the exception of one group that consists of only southern states. For total Indigenous migration flows, four communities are identified, with each community comprising states from different regions, except for one that is composed entirely of southern states.

5 | DISCUSSION

This study examines interstate origin–destination migration patterns in Mexico over the past 30 years, focusing on Indigenous and non-Indigenous populations. We estimate total interstate migration flows and subsequently use an interaction component model to highlight the flows that exceed expectations. Additionally, we apply network analysis techniques to identify the states that are central to these migration flows and categorize states into communities based on their migration patterns.

Our findings highlight two main insights: first, Indigenous and non-Indigenous populations exhibit distinct migration trends; and second, there are notable differences between total migration flows and those identified through the interaction model. Total Indigenous migration flows have typically moved from southern states like Oaxaca to central states such as Mexico City. Over time, two main patterns have emerged: first, southern states like Yucatán and Quintana Roo have become notable destinations for migrants from other southern states, leading to increased circular migration within the region. Second, Nuevo León has emerged as a major destination for Indigenous migrants. In contrast, non-Indigenous migration remains concentrated in the southern and central states, with northern states—particularly Nuevo León and Baja California—gaining importance.

Analysis of interaction component (OD_{ij}) flows revealed higher-than-expected migration patterns and some differences from the total flows. The West-Central region consistently exhibits the highest proportion of migration flows for Indigenous and non-Indigenous populations, exceeding expectations across all periods. Meanwhile, non-Indigenous migration has notably increased in interregional and intraregional flows within the South, whereas the North has seen a slight rise in Indigenous migration. Conversely, the Central region has experienced a decline in migration flows between both groups over time. The West Central region remains dominant in interregional and intraregional flows for non-Indigenous migrants.

Based on the OD_{ij} flows and network analysis, we identified key states as central hubs in Mexico's migration landscape. For Indigenous populations, states in the West Central region, such as Nayarit and Durango, stand out as influential hubs due to their high eigenvector centrality values, playing crucial roles as origins and destinations for migrants. For non-Indigenous populations, the Central region, including Mexico City and the State of Mexico, remains dominant, and northern states like Nuevo León and Baja California, are gaining in prominence. Additionally, six communities have emerged for Indigenous migrants and four for non-Indigenous migrants. Indigenous migration forms two primary communities: one in Mexico City, the State of Mexico, Tlaxcala and Puebla; and another in Guanajuato, Aguascalientes, and Querétaro. Other communities include a central-western group (Durango, Nayarit, Jalisco and Zacatecas), a southern group (Campeche, Yucatán, Quintana Roo, Tabasco and Chiapas), and two mixed-region communities.

This study corroborates previous findings about the increasing significance of Mexico's northern region within the migrant network, whether for Indigenous or non-Indigenous populations. Future research should elucidate the various factors associated with these migration flows. Significant differences likely exist in the determinants of migration, such as migrants from Veracruz (South) moving to Nuevo León (North), where the average monthly wage ratio is more than doubled, suggesting economic motivations based on expected earnings, among others. In contrast, with respect to migration flows from DGO-NAY, similar monthly average income ratios are observed between the two states, indicating that other social factors beyond economic considerations may play a more prominent role in shaping these migration patterns.[8]

Finally, it is important to acknowledge that while this study primarily focuses on internal migration within Mexico, the international migration of Mexico's Indigenous population is also a significant issue. The literature on international migration flows from Mexico to the United States is extensive, highlighting the complexities and challenges faced by Indigenous communities (Asad & Hwang, 2019; Hamilton, 2015; Ortiz, 2014; Robson et al., 2018). International migration can intensify outflows from certain regions and communities, resulting in significant social and economic consequences. A recent study by Asad and Hwang (2019) suggested that Indigenous migrants moving to the United States are often underreported in official statistics. This underreporting is partly due to the likelihood of undocumented migration among communities with substantial Indigenous populations. Further research is needed on this topic to better understand the scope and impact of international migration on Indigenous communities and address the broader implications for migration policies and support systems.

Indigenous migrants are diverse, with significant differences in cultures, origin, and destination. This diversity is crucial when examining international and internal migration patterns. While much attention has been placed on international migration, understanding internal migration dynamics is equally important. Indigenous diasporas are shaped by complex factors, such as the growth of international migration and efforts to reconstruct ethnocultural contexts (Pisani et al., 2009). However, the full extent and distinctions of these processes have not yet been fully understood. Studying international and internal migrations would provide a comprehensive view of the evolving Indigenous diaspora and help address the unique challenges faced by these communities.

Policymakers should address Indigenous communities' specific needs, including access to economic opportunities and social services, to facilitate their integration in new regions while preserving their cultural heritage. Furthermore, understanding the evolving migration dynamics can help policymakers develop effective migration management strategies, ensuring that both origin and destination states are supported when addressing the challenges and opportunities presented by internal migration.

[8]According to own estimates from the 2020 Population Census, the monthly wage for an Indigenous migrant in Nuevo León is 6880 pesos, compared to 3010 pesos in Veracruz. The estimated monthly wages in Durango and Nayarit are 4700 and 5,160 pesos, respectively.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A

TABLE A1 Abbreviations of Mexican states.

Code	State	Abbreviations	Region
1	Aguascalientes	AGS	Central
2	Baja California	BC	North
3	Baja California Sur	BCS	North
4	Campeche	CAMP	South
5	Coahuila de Zaragoza	COAH	North
6	Colima	COL	West Central
7	Chiapas	CHIS	South
8	Chihuahua	CHIH	North
9	Ciudad de México	CDMX	Central
10	Durango	DUR	West Central
11	Guanajuato	GTO	Central
12	Guerrero	GRO	South
13	Hidalgo	HGO	Central
14	Jalisco	JAL	West Central
15	México	MEX	Central
16	Michoacán	MICH	West Central
17	Morelos	MOR	Central
18	Nayarit	NAY	West Central
19	Nuevo León	NL	North
20	Oaxaca	OAX	South
21	Puebla	PUE	Central
22	Querétaro	QRO	Central
23	Quintana Roo	QROO	South
24	San Luis Potosí	SIN	West Central
25	Sinaloa	SLP	West Central
26	Sonora	SON	North
27	Tabasco	TAB	South
28	Tamaulipas	TAMPS	North
29	Tlaxcala	TLAX	Central
30	Veracruz	VER	South
31	Yucatán	YUC	South
32	Zacatecas	ZAC	West Central